PENETRATION OF SOLAR ERYTHEMAL UV RADIATION IN THE SHADE OF TWO COMMON AUSTRALIAN TREES

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Running Title: Erythemal UV in tree shade

ABSTRACT

The penetration of solar erythemal ultraviolet (UV) radiation has been measured in the shade of a gum (Eucalyptus sp.) and a she oak (Casaurina) tree, both on a horizontal plane and with polysulphone dosimeters to human anatomical sites. This has provided new data useful for protection strategies against harmful UV radiation. For larger solar zenith angles, the relative penetration of solar erythemal UV in the shade of the trees is higher. On a horizontal plane, at noon, in winter, the shade erythemal UV ranged from 44 to 55% of that in the sun whereas in spring it ranged from 29 to 37% of the irradiances in the sun. Similarly, at 9:00 EST and 15:00 EST, the shade erythemal UV in winter ranged from 51 to 81% of the irradiances in the sun whereas in spring and summer they ranged from 35 to 51% of the unshaded irradiances. The shade ratios for specific body sites provided by the shade of the two trees was 0.05 to 0.45 for the solar zenith angles in this research. The shade ratios ranged from 0.14 to 0.45 for the gum tree and from 0.05 to 0.28 for the she oak. The denser foliage of the she oak provided the higher UV protection compared to that of the gum tree.

Key words: ultraviolet; erythema; tree shade; dosimeters

INTRODUCTION

One of the strategies recommended by Health authorities for reduction of the exposure to solar erythemal ultraviolet (UV) radiation is the making use of shade. The UV radiation under shadecloth has been investigated (Wong 1994; Wong et al, 1994). The protection provided by hats has also been reported (Wong et al, 1996; Diffey and Cheeseman 1992). During outdoor sporting and recreational activities when hats are not worn, the general population may seek to shelter from the sun in the shade of a tree. The biologically active radiation, namely, photosynthetically active radiation, along with UVB and UVA has been investigated in the vicinity of a tree (Grant 1977). Despite the intuitive understanding that the shade of a tree will reduce the exposure to solar erythemal ultraviolet radiation, there is no quantitative data on the penetration of solar erythemal UV in the shade of a tree and no data on the resultant personal exposures.

Of primary concern in outdoor exposure is the face which is not covered by clothing. Manikin and head form studies have been previously employed to measure the erythemal exposure to various anatomical body sites on the face (Wong et al, 1992; Diffey et al, 1977; Gies et al, 1988; Holman et al, 1983). Airey et al, (1995) found that various human activities may be simulated for erythemal exposure measurements by tilting the headform to various angles. In this paper, the activities of a human in a predominantly upright position will be considered to provide quantitative data on the exposure to the facial area and other body sites from solar erythemal UV radiation penetrating the shade of a tree.

MATERIALS AND METHODS

The Trees

Two individual evergreen trees of comparable size and relatively isolated from other trees were selected in the grounds of the University of Southern Queensland campus, Toowoomba, (27.5^o S latitude). The dimensions of the two trees are: gum (Eucalyptus sp.) height, 7.1 m, crown diameter, 5.7 m and height to crown, 2.4 m; she oak (Casaurina) height, 6.3 m, crown diameter, 6.0 m and height to crown, 0.0 m. The gum was selected to be representative of a species that is abundant in Australia and the she oak was selected to provide a tree that is also abundant in Australia, but with a denser foliage. The height of the crown was obtained by trigonometry and the other parameters measured directly.

Irradiance Measurements

The spatial variation of the ambient UV irradiances on a horizontal plane at ground level in the erythemal (CIE, 1987) and UVA (320-400 nm) wavebands were measured with a detector (Model 3D V2.0, Solar Light Co., Philadelphia, USA) fitted with an erythemal sensor and an UVA sensor. The measurements were taken at grid points with a one metre separation in the shade of each tree at 9:00 Australian Eastern Standard Time (EST), 12:00 EST and 15:00 EST in late winter to spring and summer on the dates in column 1 of Table 1. The measurement on each tree was completed within 10 minutes. During this period, the variation in the ambient radiation was less than 10%. The solar zenith angles (SZA) for each time on each date are provided in column 4 of Table 1. On each day and time in the Table, the sky was relatively free of cloud with the amount of cloud cover at 9:00 EST and 15:00 EST on each day being 1 okta or less (okta meaning one-eighth of the sky dome, WMO, 1983). At noon and

15:00 on 21 January, there was appreciable cloud and the data have not been included. At the same time as measuring the erythemal and UVA irradiances, the irradiances in the visible waveband in units of LUX were measured with a Luxmeter (Model EMTEK LX-102, supplier, Walsh's Co., Brisbane, Australia) that has a response approximating that of the human eye.

Personal Erythemal Exposures

Polysulphone film (Diffey 1989) in a holder 3 cm x 3 cm was employed in dosimeters to measure the erythemal exposure and was calibrated as described elsewhere (Kimlin et al, 1998) against a meter measuring erythemal irradiance (Model 3D V2.0, Solar Light Co., Philadelphia, USA). The sites employed on the manikin were the bridge of the nose, cheek, chin, chest, left shoulder, left lower arm, left thigh and the left lower leg. A dosimeter was exposed on a horizontal plane at ground level in a shaded position along with one in an unshaded position in full sunshine. Details of the measurement dates from spring to summer and the noon solar zenith angles for the personal erythemal exposure measurements are provided in Table 1. On each measurement day, the exposures were measured between 9:00 EST and 15:00 EST and the dosimeters changed at 12:00 EST each day to prevent saturation of the polysulphone film. The manikin was in an upright position and rotated on a rotating platform at approximately 1 to 2 revolutions/minute to simulate a human in a predominantly upright position. The manikin was moved throughout the day in order to maintain it in a shaded location as the shadow of the tree shifted throughout the period. This is analagous to humans who will generally move to remain in the shade as the shadow shifts.

The shade ratio, T_s (Wong 1994) defined as:

$$T_S = \frac{UVBE_S}{UVBE} \qquad (1)$$

was calculated for each anatomical site, where $UVBE_s$ is the erythemal exposure to the shaded body site and UVBE is the ambient erythemal exposure to an unshaded horizontal plane.

RESULTS

Irradiance Measurements

The irradiances on a horizontal plane averaged over all the grid points in the tree shade are provided in columns 5 to 7 of Table 1 with one MED defined as 20 mJ cm^{-2} (Diffey 1992) and is the amount of biologically effective UV required to produce barely perceptible erythema after an interval of 8 to 24 hours following UV exposure. The plus and minus value is one standard deviation of the average values. The largest variation in the measured values is for the visible irradiance with the largest percentage standard deviation of 88% of the average value. In comparison, the smallest variation in the measured values was for the erythemal irradiances with the largest variation being 40% of the average value.

In Table 1, the erythemal irradiances in the shade of both trees have been normalised by the unshaded erythemal irradiances for each measurement day. The normalised irradiances at noon on 13 and 14 August are 0.51 and 0.44 for the gum and she oak trees respectively. Similarly, at noon on the 9 and 13 October, the normalised irradiances are 0.29 and 0.37 for the she oak and gum trees respectively. The solar zenith angles at noon on the dates in August and October are approximately the same.

For this case the major contributing factor to the difference in the normalised irradiances is most likely the higher density of foliage on the she oak tree. This resulted in the lower normalised erythemal irradiance for the she oak tree.

Solar Zenith Angle

The normalised erythemal irradiances in Table 1 in winter at noon on 13 and 14 August range from 44 to 51% of the irradiances in the sun. In comparison, the irradiances in the shade in spring at noon on the 9 and 13 October are lower and range from 29 to 37% of the irradiances in the sun. This difference is most likely due to a higher proportion of diffuse radiation in the total erythemal component in winter as a result of the higher SZA. This is supported by the normalised erythemal irradiances in the shade increasing either side of noon on each day for the measurements at 9:00 EST and 15:00 EST. For example, the normalised erythemal irradiances in the shade of the she oak on 14 August almost doubles from 0.44 to 0.81 for 12:00 EST and 15:00 EST respectively.

The ratio of the erythemal UV irradiance in the shade to the UVA irradiance in the shade is also provided in Table 1. This ratio is also dependent on the SZA with the highest value at noon on the cloud free days of this research. Specifically, relative to the UVA waveband in the shade, the erythemal UV waveband comprises a larger component at the smaller SZA at noon. A plot of the rates of erythemal UV to UVA in the shade versus the SZA is provided in Figure 1(a). For the relatively clear sky conditions of this study, this ratio is reasonably correlated to the SZA with an R-squared value of 0.80 for the linear model fitted to the data, as follows:

$$\frac{UVBE_s}{UVA_s} = -0.016 * \mathrm{SZA} + 1.50 \qquad (\mathrm{MED\ hr^{-1}/mW\ cm^{-2}}) \qquad (2)$$

The slope of this fitted model has a higher absolute value than the slope (-0.0096, calculated from the data collected in this research) for the model for the same ratio in the sun. The ratio of the two wavebands has a different dependence on the SZA in the shade compared to the ratio of the two wavebands in the sun.

A plot of the erythemal irradiances in the tree shade as a function of SZA is provided in Figure 1(b). The diffuse UV radiation affects the penetration of erythemal UV into the tree shade. The amount of this diffuse radiation is influenced by the SZA. The model obtained for the relatively clear sky conditions in this study is:

$$UVBE_s = -0.022 * SZA + 1.96 \qquad (MED\ hr^{-1}) \qquad (3)$$

with an R-squared value of 0.74. The rate of decrease in $UVBE_s$ with SZA is less than the rate of decrease (-0.083, calculated from the data in this research) of UVBE with SZA in full sun. This fitted model provides an estimate of the effect of the scattered UV radiation on the penetration of erythemal UV in the tree shade.

Tree Shade and Full Sun Erythemal Irradiances

The relationship between the erythemal irradiances on a horizontal plane in the shade and the erythemal irradiances in full sun at the sub-tropical latitude of this research have been combined for the two trees in this study and is provided in Figure 2. The linear model fitted to the data is:

$$UVBE_s = 0.27 * UVBE + 0.36 \qquad (MED\ hr^{-1}) \qquad (4)$$

with an R-squared value of 0.81.

Personal Erythemal Exposures

The personal erythemal exposures between 9:00 EST and 15:00 EST to the body sites in the shade and the shade ratios are provided in Table 2. Relatively high exposures that are higher than the limits set by the National Health and Medical Research Council of Australia (NHMRC 1989) as the occupational standard for UV exposure were received to the anatomical sites in both the spring and summer of this research. The highest exposure in spring was 5.9 MED over a six hour period to the shoulder in the shade of the she oak on 22 October and the highest in summer was 8.5 MED over a six hour period to the lower arm in the shade of the gum on 3 February.

DISCUSSION

The result of measurements in the shade of two common Australian trees suggested that erythemal irradiance for a horizontal plane in the shade decreases with the increase in solar zenith angle. For relatively clear skies at a sub-tropical latitude the decrease was 0.022 MED hr^{-1} per degree. This rate of decrease is approximately a quarter of the decrease with solar zenith angle in full sun. Specifically, for larger solar zenith angles, the relative penetration of solar erythemal UV in the shade of the tree is higher. On a horizontal plane, at noon, in winter, the $UVBE_s$ ranged from 44 to 55% of those in the sun whereas in spring they ranged from 29 to 37% of the irradiances in the sun. Similarly, at 9:00 EST and 15:00 EST, the $UVBE_s$ ranged from 51 to 81% of the irradiances in the sun whereas in spring and summer they ranged from 35 to 51% of the unshaded irradiances. The results suggest that the trees screen off mainly the direct radiation from the sun, but most of the indirect radiation is present below the canopy of the tree. The large variation in the visible irradiances is due to the presence of sunflecks from unobstructed sunlight or with a reduced intensity due to penumbra from leaves and branches (Grant 1997). These sunflecks vary both spatially and also temporally as a result of wind and changes in solar zenith angle. These sunflecks have a larger effect in the visible irradiance compared to the erythemal irradiance due to the higher proportion of diffuse radiation in the erythemal waveband and results in the larger relative standard deviation for the visible waveband. Consequently, the erythemal UV in tree shade is not directly proportional to the visible irradiance. At the higher solar zenith angles, the degree of scattering of the UV waveband from the leaves may also be higher. In terms of the protection provided by the two types of common Australian trees in this research, they provide more relative protection from solar UV in spring compared to winter with the solar UV at noon reduced to approximately half of that in full sun by the shade in winter and reduced to approximately one third in spring. Similarly, the trees provide more relative protection at noon compared to earlier or later in the day.

The results from this research have quantified the shade ratios for specific body sites provided by the shade of the two trees as 0.05 to 0.45 for the solar zenith angles in this research. For the shoulder, these range from 0.18 to 0.45, compared to ranges of 0.68 to 0.80 (Diffey et al, 1977), 0.89 to 0.99 (Gies et al, 1988) and 0.66 to 0.70 (Holman et al, 1983) for exposures in full sun. Similarly, for the chest, the range is 0.14 to 0.32, compared to 0.58 to 0.73 (Diffey et al, 1977), 0.42 to 0.58 (Gies et al, 1988) and 0.44 to 0.46 (Holman et al, 1983). The ratios for the human body sites in the shade of the tree are lower than those without the protection of the shade. The ratios ranged from 0.14 to 0.45 for the gum tree and from 0.05 to 0.28 for the she oak. The denser foliage of the she oak provided the higher UV protection compared to that of the gum tree. Despite the protection to humans from solar erythemal ultraviolet radiation provided by the shade of a tree, considerably high erythemal exposures to human body sites in the shade of trees were measured in spring and summer. Over a six hour period centred around noon, these exposures are higher than the occupational standard for UV exposure with a maximum of 5.9 MED in spring and 8.5 MED in summer. From this research, although tree shade provides some UV protection, it may not be as high as the general public may think. Additional protection by the application of sun-cream should not be overlooked in group activities employing tree shade such as school sports for young children. The amount of UV penetrating the tree shade is less for a tree with denser foliage and for a given tree it is higher for larger solar zenith angles and cloudy days.

REFERENCES

Airey, D. K.; Wong, J. C. F.; Fleming, R. A. A comparison of human- and headform-based measurements of solar ultraviolet B dose. Photodermatol. Photoimmunol. Photomed. 11:155-158; 1995.

CIE (International Commission on Illumination). A reference action spectrum for ultraviolet induced erythema in human skin. CIE J. 6:17-22; 1987.

Diffey, B.L. Stratospheric ozone depletion and the risk of non-melanoma skin cancer in a British population. Phys. Med. Biol. 37:2267-2279; 1992.

Diffey, B. L. Ultraviolet radiation dosimetry with polysulphone film In: Diffey B. L., ed. Radiation Measurement in Photobiology. New York: Academic Press; 1989: 136-159.

Diffey, B. L.; Cheeseman, J. Sun protection with hats. Br. J. Dermatol. 127:10-12; 1992.

Diffey, B. L.; Kerwin, M.; Davis, A. The anatomical distribution of sunlight. Br. J. Dermatol. 97:407-410; 1977.

Gies, P.; Roy, C.; Elliot, G. The anatomical distribution of solar UVR with emphasis on the eye. Proc. 7th Cong. IRPA 10-17th April, 1: 341-344; 1988.

Grant, R. H. Biologically active radiation in the vicinity of a single tree. Photochem. Photobiol. 65:974-982; 1997.

Holman, C. D. J.; Gibson, I. M.; Stephenson, M.; Armstrong, B. K. Ultraviolet irradiation of human body sites in relation to occupation and outdoor activity: field studies using personal UVR dosimeters. Clin. Exp. Dermatol. 8:269-277; 1983.

Kimlin, M. G.; Wong, J. C. F.; Parisi, A. V. Simultaneous comparison of the personal UV exposure of two human groups at different altitudes. Health Phys. 74:429-434; 1998.

NHMRC (National Health and Medical Research Council) Occupational standard for exposure to ultraviolet radiation. Radiation Health Series No.29. Canberra 1989.

Wong, C. F. Scattered ultraviolet radiation underneath a shade-cloth. Photodermatol. Photoimmunol. Photomed. 10:221-224; 1994.

Wong, C. F.; Fleming, R. A.; Carter, S. J.; Ring, I. T.; Vishvakarman, D. Measurement of human exposure to ultraviolet-B solar radiation using a CR-39 dosimeter. Health Phys. 63:457-461; 1992.

Wong, C. F.; Fleming, R. A.; Thomas, B. W. Relation of dose measurements to indexing protective devices for exposure to solar radiation. SPIE Ultraviolet Radiation Hazards. 2134B:113-119; 1994.

Wong, C. F.; Airey, D. K.; Fleming, R. Annual reduction of solar UV exposure to the facial area of outdoor workers in Southeast Queensland by wearing a hat. Photodermatol. Photoimmunol. Photomed. 12:131-135; 1996.

WMO Guide to Meteorological Instruments and Methods of Observation. World Meteorological Organisation, WMO No. 8, 5th Edition, Chapter 11: 11.2; 1983.

Table 1. Irradiances in the tree shade and in the sun on a horizontal plane.

Date	Time (EST)	Tree	SZA (°)	Irradiances in the tree shade: Erythemal (MED hr^{-1})	UVA ($mW\ cm^{-2}$)	Visible (LUX x 100)	Shade Erythemal /Sun Erythemal	Shade Erythemal /Shade UVA (MED hr^{-1}/$mW\ cm^{-2}$)
13 Aug 97[(a)]	09:00	Gum	60	0.60±0.06	1.07±0.17	78±40	0.54	0.56
13 Aug 97[(a)]	12:00	Gum	42	1.2±0.2	1.5±0.7	82±32	0.51	0.84
13 Aug 97[(a)]	15:00	Gum	61	0.53±0.07	0.9±0.2	75±59	0.76	0.56
14 Aug 97[(a)]	09:00	She oak	60	0.52±0.09	1.0±0.2	72±50	0.51	0.52
14 Aug 97[(a)]	12:00	She oak	42	1.0±0.3	1.0±0.3	86±71	0.44	0.97
14 Aug 97[(a)]	15:00	She oak	61	0.48±0.11	1.0±0.3	91±41	0.81	0.48
9 Oct 97[(b)]	09:00	She oak	44	0.9±0.3	1.5±0.7	147±129	0.35	0.61
9 Oct 97[(b)]	12:00	She oak	22	1.2±0.4	1.0±0.4	111±79	0.29	1.1
9 Oct 97[(b)]	15:00	She oak	52	0.76±0.19	1.1±0.5	70±51	0.47	0.68
13 Oct 97[(c)]	09:00	Gum	42	1.12±0.11	1.37±0.17	91±34	0.47	0.82
13 Oct 97[(c)]	12:00	Gum	20	1.5±0.3	1.4±0.3	81±38	0.37	1.1
13 Oct 97[(c)]	15:00	Gum	51	0.83±0.11	1.3±0.3	103±64	0.59	0.66
21 Jan 98[(d)]	09:00	Gum	43	1.5±0.2	1.5±0.4	136±117	0.37	1.0
21 Jan 98[(d)]	09:00	She oak	43	1.0±0.4	1.0±0.4	55±32	0.51	0.98

Mean SZA time: (a) 12:05 EST, (b) 11:47 EST, (c) 11:46 EST and (d) 12:11 EST.

Table 2. Personal erythemal exposures to the body sites in the shade and shade ratios for each of the five days.

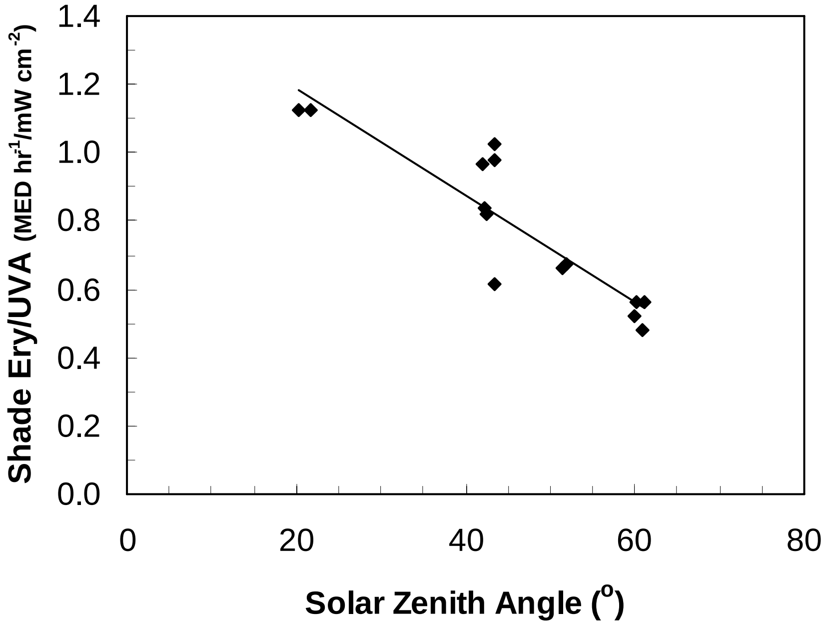
Site	Gum (22 Sept 97) Noon SZA 28^o		She Oak (23 Sept 97) Noon SZA 28^o		She Oak (22 Oct 97) Noon SZA 17^o		She Oak (2 Feb 98) Noon SZA 11^o		Gum (3 Feb 98) Noon SZA 11^o	
	Exposure (MED)	Shade Ratio	Exposure (MED)	Shade Ratio	Exposure (MED)	Shade Ratio	Exposure (MED)	Shade Ratio	Exposure (MED)	Shade Ratio
nose	4.4	0.37	1.5	0.09	3.9	0.19	4.0	0.18	6.8	0.28
cheek	2.5	0.21	0.8	0.05	3.0	0.14	1.7	0.08	3.4	0.14
chin	1.7	0.14	1.4	0.08	1.8	0.09	2.6	0.11	3.6	0.15
shoulder	5.4	0.45	3.1	0.18	5.9	0.28	4.9	0.22	8.0	0.33
chest	3.8	0.32	2.4	0.14	5.5	0.26	4.4	0.20	7.3	0.30
l. arm	2.8	0.23	3.6	0.21	4.1	0.20	5.3	0.24	8.5	0.35
thigh	3.5	0.30	2.0	0.12	4.4	0.21	3.5	0.16	5.6	0.23
leg	1.7	0.14	1.8	0.09	2.3	0.11	2.8	0.12	4.2	0.17

Figure Captions

Figure 1. (a) The ratio of the erythemal to UVA irradiances in the shade as a function of the solar zenith angle and (b) the erythemal irradiance in the tree shade as a function of the solar zenith angle.

Figure 2. The erythemal irradiances in the tree shade versus the erythemal irradiances in the sun on a horizontal plane.

(a)


1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Shade Ery/UVA (MED hr^{-1}/mW cm^{-2})
0
20
40
60
80
Solar Zenith Angle (^{o})

(b)

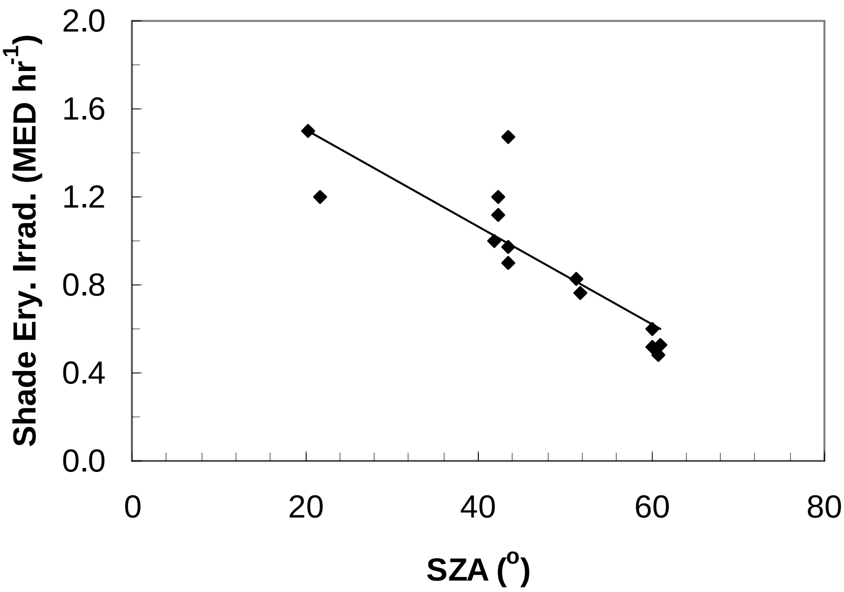

2.0
1.6
1.2
0.8
0.4
0.0
Shade Ery. Irrad. (MED hr^{-1})
0
20
40
60
80
SZA (^{o})

Figure 1

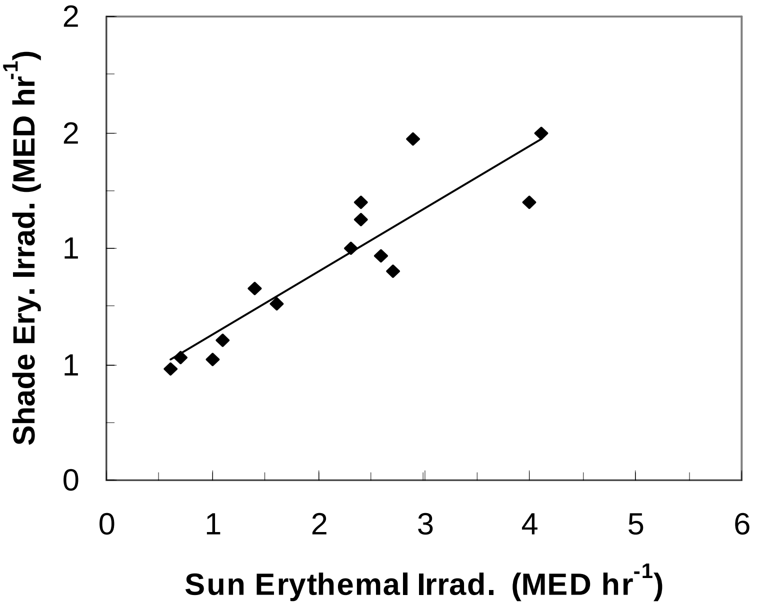

Shade Ery. Irrad. (MED hr-1)
Sun Erythemal Irrad. (MED hr-1)
2
2
1
1
0
0
1
2
3
4
5
6

Figure 2